NATURAL GAS *brief*

JUNE 2020

Stanford | Natural Gas Initiative
School of Earth, Energy & Environmental Sciences and Precourt Institute for Energy

Methane emissions from the U.S. oil and gas system likely exceed 2% of production. Airplane-based remote sensing tools could detect as much as 50% or more of emissions from oil and gas production and midstream by focusing on "super-emitting" point sources.

PHOTO CREDIT | Kairos Aerospace

Finding super-emitting natural gas leaks from the sky—

By Evan Sherwin and Adam Brandt, Stanford University

A growing body of research suggests that **more than 2% of all natural gas** produced in the United States leaks into the atmosphere before reaching the end customer. This is about 600 billion cubic feet, equivalent to annual gas consumption in Virginia. Preventing these emissions can substantially reduce the climate impacts of the oil and gas system while potentially saving money by preserving this valuable product.

At present, finding which facilities and components are leaking is a costly and labor-intensive process. There are over a million active oil and gas wells in the United States connected to hundreds of thousands of miles of gathering and transmission pipelines, as well as support infrastructure such as gas processing facilities. Gas is typically ▸

ABOUT THE AUTHORS

Evan Sherwin is a Postdoctoral Research Fellow in the Department of Energy Resources Engineering at Stanford University studying the role of hydrocarbon fuels in a rapidly decarbonizing economy. His current focus is assessing and demonstrating the value of diverse methane emission sensing technologies across the oil and gas value chain in an increasingly data-rich environment. Evan has PhD in Engineering and Public Policy and an MS in Machine Learning from Carnegie Mellon University.

Adam Brandt has a PhD from UC Berkeley and is an Associate Professor in the Department of Energy Resources Engineering, Stanford University. His research focuses on reducing the greenhouse gas impacts of energy production and consumption, emphasizing fossil energy systems. Research interests include life cycle assessment of petroleum production and natural gas extraction. A particular interest is in unconventional fossil fuel resources such as oil sands, oil shale and hydraulically fractured oil and gas resources. He also researches computational optimization of emissions mitigation technologies, such as carbon dioxide capture systems.

For more information

Evan Sherwin:
https://profiles.stanford.edu/evan-sherwin

Adam Brandt:
https://profiles.stanford.edu/adam-brandt

Natural Gas Briefs:
ngi.stanford.edu/briefs

Timestamped false color plumes of methane with the true methane release rate in kilograms of methane per hour (kgh) and the wind speed in meters per second (mps). Conducted at a test site near Stockton, CA on an airstrip next to agricultural fields. Note that the scale changes on the bottom row to ensure the image captures these larger plumes.

not odorized before reaching municipal customers, making leaks more difficult to detect in production, processing, and transmission than in cities. Current leak detection and repair methods generally require ground crews operating specialized handheld equipment, limiting the number of facilities that can reasonably be surveyed in a given year.

That said, the results of such field surveys suggest that an outsized fraction of natural gas emissions from oil and gas infrastructure come from a small number of "super-emitters." While the precise numbers vary across regions, as a rule of thumb about 5% of sources account for about 50% of total emissions. Because these leaks are large, they are likely quite profitable to fix. Thus, a rapid screening system capable of finding only these super-emitting sources could allow oil and gas operators to identify and fix the sources responsible for about half of their emissions.

Remote sensing from aircraft or satellites has the potential to do just that. Thankfully methane, the main component of natural gas, has a distinct radiation signature, for the same reason it is a powerful greenhouse gas, making it well-suited for these applications. Remote systems from the air generally have lower sensitivity than ground-based methods but can survey large areas much more quickly. A small airplane can cover hundreds of square miles and well over a thousand wells in a day. Ground crews typically visit less than ten sites per day. A satellite can cover the entire globe in less than two weeks.

DOES IT WORK?

With support from Stanford's Natural Gas Initiative, we conducted an independent single-blind field trial of an airplane-based methane remote sensing system produced by Mountain View-based Kairos

Evan Sherwin calibrates natural gas flow meters at the pressure and temperature regulator trailer, through which we released gas from pressurized trucks, with help from technician Jeff Gamble of Rawhide Leasing. The three-meter setup allows us to maintain reliable measurements at a wide range of gas release volumes.

Aerospace, aiming to determine how accurately their system can detect and quantify methane emissions at different rates. A preprint of the results is available on the EarthArXiv server while the paper undergoes peer review.

Over four days of testing, we released about seven tons of methane at a farm in the Sacramento-San Joaquin River Delta, varying the release rate as Kairos flew overhead. Kairos tried to detect and quantify emissions without access to data on release rates, working entirely from what they could see from the airplane (a "single blind" controlled experiment). Kairos' technology uses pictures of methane plumes to estimate the release of methane in units of methane emissions per unit wind speed, which we convert to absolute emissions using several different measurements and estimates of wind speed.

Depending on the wind speed, Kairos could detect emissions as low as 20 kilograms of methane per hour (kgh), about 27 thousand cubic feet per day (mcfd) of natural gas, valued at $54 per day at $2/mcf. Kairos detected all emissions above 200 kgh (~270 mcfd, $540 per day).

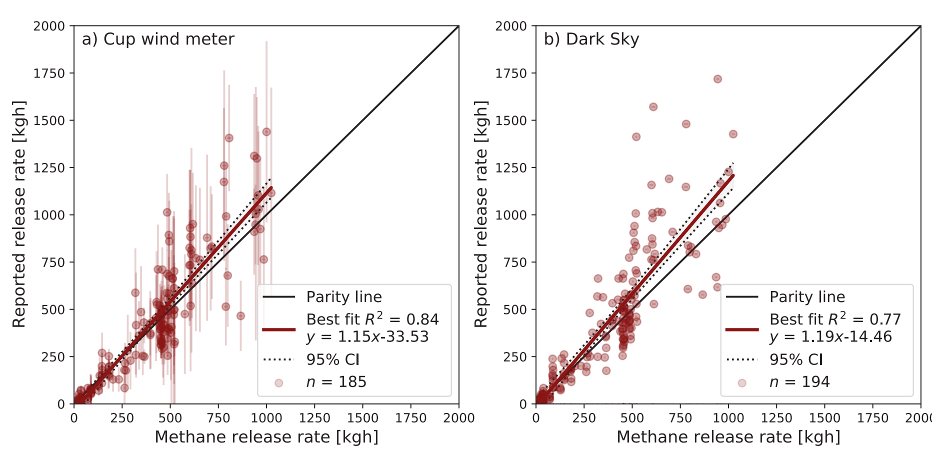
Based on observations in the field, we tested a wide range of emission levels with the largest releases above 1,000 kilograms per hour, about 1,350 mcfd or $2,700 per day. Kairos' field surveys suggest that the largest emissions in the field could be as much as 25 times larger than even this.

Figure 1a) shows relatively close average agreement between Kairos' quantification v. measured release rates. The slope of the linear fit is 1.15, with an R^2 value of 0.84, both close to the ideal value of 1, demonstrating that a linear fit explains the relationship between the two quantities fairly well. This slope changes somewhat depending on the wind speed measurement used to generate total emissions but the R^2 remains high and this bias can easily be corrected for. Kairos retains relatively strong quantification performance (slope = 1.19, R^2 = 0.77) even if on-the-ground wind measurements are replaced with commercially available high-resolution estimates of local wind speed, such as those from Dark Sky, shown in Figure 1b).

Figure 1: Measured emission rates v. Kairos' estimates

a) A scatter plot of the measured methane release rate (x-axis) and the wind speed-normalized release rate reported by Kairos multiplied by ground-based wind speed measurements. The best-fit line is close to the ideal slope of 1 with a relatively close fit. Error bars for each point are due to wind measurement uncertainty.

b) The same scatter plot using commercially available modeled wind data from Dark Sky instead of on-the ground measurements, suggesting that the technique is still fairly accurate.



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> *"A study conducted by Stanford University researchers provided unequivocal evidence that the company's technology accurately and reliably identifies the large sources of methane that are responsible for 50 to 90 percent of total methane emissions in the field."*
>
> *—BusinessWire*

UNLOCKING BASIN-WIDE SURVEYS

Methane quantification is a hard problem. There is considerable uncertainty, largely due to wind, which affects most methane detectors, particularly remote sensing tools. Kairos' quantification estimates of the amount of methane emitted have a 95% confidence interval of about ±75%. Because of the relatively close average fit between Kairos' measurements and the ground truth, the error surrounding an individual emission may be fairly large but the error for a survey of many potentially leaking assets will produce a relatively tight estimate of overall emissions from a broader region.

What fraction of methane emissions could this kind of technology find? Using a compilation of over 1,000 field measurements from eight U.S. basins (Omara et al. 2018), and assuming modest winds of 2 meters per second (mps), we estimate that Kairos could detect and quantify >50% of total emissions from the dataset. At stronger winds of 4 mps, this falls to 41% of total emissions, and 32% of emissions at 7 mps, the maximum wind speed at which it is safe for these airplane-based surveys. While it is not known whether that dataset is truly representative of U.S. average conditions, and actual results will vary across basins, this preliminary work suggests that remote sensing could likely identify leaks responsible for a large fraction of total emissions.

Press coverage of Kairos' latest $9 million investment round mentioned our preprint, highlighting the role of NGI-funded independent academic research in fostering the development and deployment of cutting-edge tools for industry.

MORE REMOTE SENSING TO COME

Remote sensing will not find all of the methane emission sources in upstream and midstream oil and gas operations, and certainly in local distribution systems where leaks will be smaller and underground. More sensitive methods are still necessary for those applications. However, our field trial demonstrates that airplane-based remote sensing can reliably detect and quantify the largest few percent of emission sources, which often account for about half of total methane emissions from an oil- or gas-producing basin.

In addition to airplane-based methods, methane sensing satellites are rapidly entering the scene. GHGSat launched its first satellite in 2016. The Environmental Defense Fund and Bluefield both plan to begin launching satellites in the next few years. These satellites raise the prospect of rapid, continuous screening of large methane emission sources from the entire global oil and gas sector and beyond. ■ ▶

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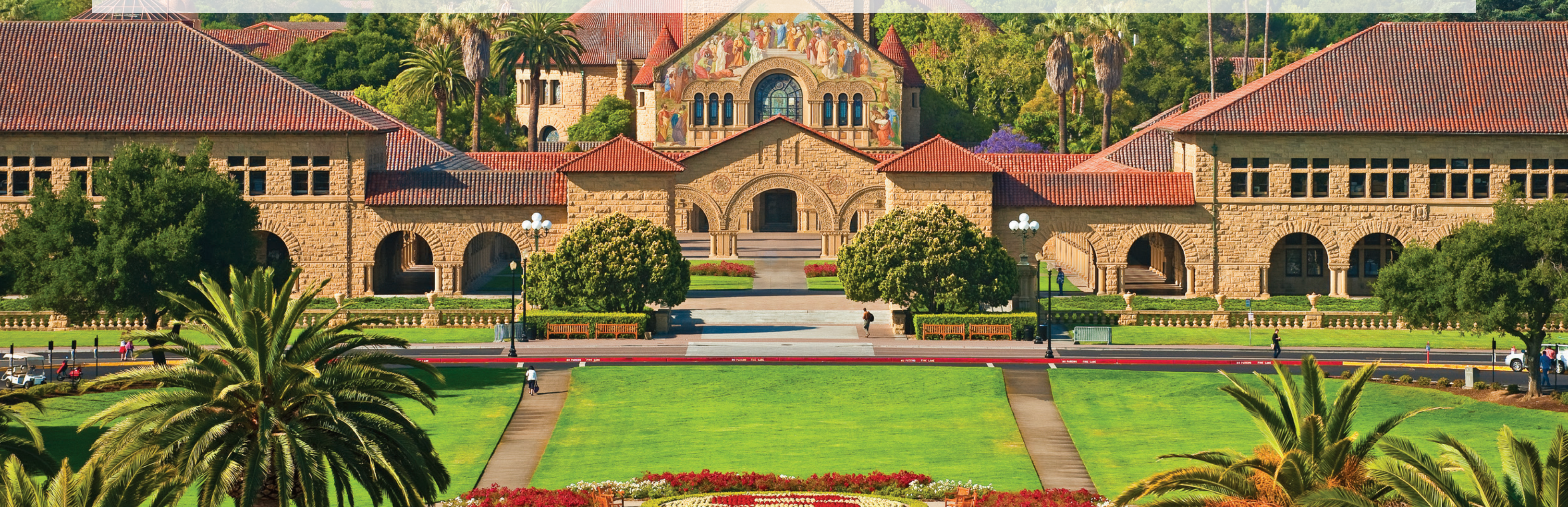
THE NATURAL GAS INITIATIVE AT STANFORD

Major advances in natural gas production and growth of natural gas resources and infrastructure globally have fundamentally changed the energy outlook in the United States and much of the world. These changes have impacted U.S. and global energy markets, and influenced decisions about energy systems and the use of natural gas, coal, and other fuels. This natural gas revolution has led to beneficial outcomes, like falling U.S. carbon dioxide emissions as a result of coal to gas fuel switching in electrical generation, opportunities for lower-cost energy, rejuvenated manufacturing, and environmental benefits worldwide, but has also raised concerns about global energy, the world economy, and the environment.

The Natural Gas Initiative (NGI) at Stanford brings together the university's scientists, engineers, and social scientists to advance research, discussion, and understanding of natural gas. The initiative spans from the development of natural gas resources to the ultimate uses of natural gas, and includes focus on the environmental, climate, and social impacts of natural gas use and development, as well as work on energy markets, commercial structures, and policies that influence choices about natural gas.

The objective of the Stanford Natural Gas Initiative is to ensure that natural gas is developed and used in ways that are economically, environmentally, and socially optimal. In the context of Stanford's innovative and entrepreneurial culture, the initiative supports, improves, and extends the university's ongoing efforts related to energy and the environment.



Join NGI

The Stanford Natural Gas Initiative develops relationships with other organizations to ensure that the work of the university's researchers is focused on important problems and has immediate impact. Organizations that are interested in supporting the initiative and cooperating with Stanford University in this area are invited to join the corporate affiliates program of the Natural Gas Initiative or contact us to discuss other ways to become involved. More information about NGI is available at ngi.stanford.edu or by contacting the managing director of the initiative, Naomi Boness, Ph.D. at naomi.boness@stanford.edu.